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Mobile phone infrastructure development: Lessons for the development of a hydrogen infrastructure

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ABSTRACT

The development of new infrastructure is often a consideration in the introduction of new innovations. Currently there is some confusion around how to develop a hydrogen infrastructure to support the introduction of FCVs. Lessons can be learned from similar technology introduction in the past and therefore this paper investigates how mobile phone infrastructure was developed allowing the mass-market penetration of mobile phones. Based on this successful infrastructural development suggestions can be made on the development of a hydrogen infrastructure. It is suggested that a hydrogen infrastructure needs to be pre-developed 3–5 years before the market introduction of FCVs can successfully occur. A lack of infrastructural pre-development will cause to the market introduction of FCVs to fail.

Introduction

The development of infrastructure to support new technologies and products is an integral aspect in the introduction of innovations. Many innovations would be useless without their associated infrastructure. A clear example of this is Fuel Cell Vehicles (FCVs). There is great interest in the development of hydrogen infrastructure to support FCV market entry [1–4]. Many case studies aim at solving some of the current issues of infrastructural development by investigating historical cases. Previous studies use the example of how internal combustion engine (ICE) vehicle infrastructure was developed in the late 1800s and early 1900s [5,6]. However, these examples are less helpful to the current situation. One reason for the success of the ICE was due to there being an existing petroleum supply network. This network supplied petroleum for lighting and for stationary petrol generators, as well as the farming industry [5]. This meant that ICE outcompeted BEVs and steam engine vehicles precisely because infrastructure was already present. The availability of infrastructure was a compelling reason to purchase an ICE vehicle over competitive vehicles. This example can be useful to some new automotive technologies; for example, BEVs can make use of existing domestic electricity supplies, albeit with lower charge rates. FCVs require a totally new refuelling infrastructure. Furthermore, hydrogen is a commodity that is not supplied by the current transport fuel industry but by specialised companies. These might see new business opportunities and become new players within the automotive fuel industry. This means that the example of the development of petroleum supply networks is less helpful. What is needed is an example of a new infrastructure being developed to support an innovation that had no prior infrastructure available. Fortunately, a very instructive example

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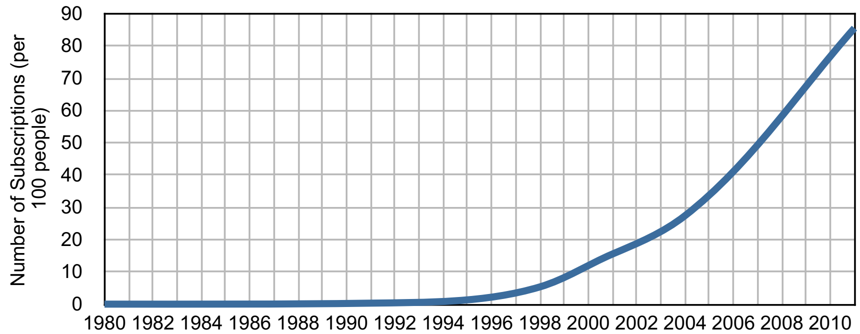

Fig. 1 — Global Mobile Phone Subscriptions per 100 people [13].

exists, this being the mobile phone and its network infrastructure. The mobile phone was a disruptive innovation heavily reliant upon infrastructure for it to gain success. FCVs share this characteristic as they are a potentially disruptive innovation [7] and are heavily reliant upon infrastructure.

Understanding how mobile communication networks were developed will allow us to learn exactly how new infrastructure is implemented and how the decision to heavily invest can be made; the hope is that these lessons can be applied to any disruptive or innovative infrastructure. The results here can be used to convince stakeholders to invest in hydrogen infrastructure. This paper will show that predevelopment of infrastructure is vital to the successful introduction of any innovations requiring totally new infrastructure. This is highlighted by the fact that network development began 5 years before the first mobile phone was sold to the public.

Disruptive innovation

The mobile phone was a disruptive innovation; this can be confirmed using the 3-point disruptive technology criteria. The criteria states that innovations are disruptive innovations if they require new infrastructure, are produced by new market entrants and not incumbents, and provide a greater level of service to the end users [7]. The mobile phone is aligned well to the three criteria. Clayton Christensen, the founder of disruptive innovation theory, also states that mobile phones are a disruptive innovation to land line telephones [8]. Mobile phones had clear added functionality over landline phones; this functionality did however come at a high price. But with economies of scale and technological improvements handset unit costs were continually reduced and in around 30 years the mobile phone went from high cost low volume series in niche markets to occupying the whole landscape and achieving an enormous mass-market share (see section 1.2).

When the team at Motorola headed by Martin Cooper invented the mobile phone [9], it created a new market sector. The mobile phone had clear added value. The mobile phone met an existing need: it became possible to instantly communicate regardless of location, and be able to contact people in the event of an emergency situation. The mobile phone provided convenience greater than any other communication technology did before. Land lines, phone booths and pagers could not meet these needs. The cost of using a mobile phone far exceeded the costs of communication via landline, but people were willing to pay due to the added convenience. One further reason the mobile developed added value was thanks to it becoming a status symbol [10].

Mobile phones generate revenue at the point of sale, and provide continuous revenue in the form of service charges throughout their use. By 2015 the global mobile phone handset market is expected to reach \$340 billion [11]. The extent of market penetration of mobile phones is vast. Globally there are 85 phone subscriptions per 100 people. In developed countries like the UK 39% of people own a smart phone and there are more phone subscriptions than inhabitants. 52% of voice communications are now made via a mobile phone [12]. Figs. 1 and 2 show the global and UK increases in phone

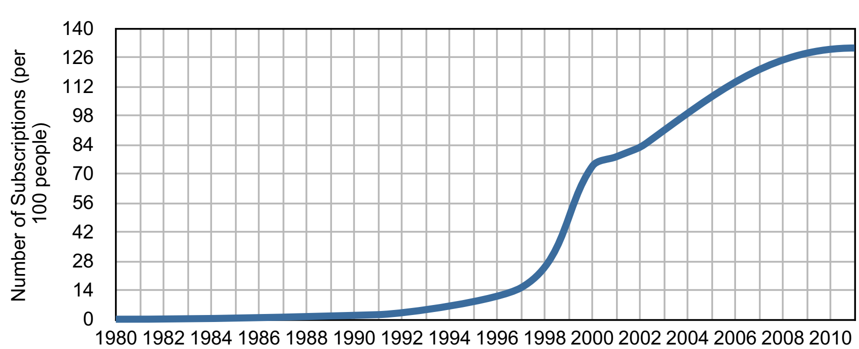

Fig. 2 — UK Mobile Phone Subscriptions per 100 people; note that there are more subscriptions than inhabitants in the UK. This is because many people have more than one phone, or SIM card [13].

subscriptions in the telecommunications sector as a measure of the mobile phone market. In the UK it can be seen that growth has begun to slow and the market may have almost reached saturation. The recent global growth trend in mobile phone subscriptions is being maintained by emerging economies.

Rapid product development

The first mobile phone calls were made from cars in the 1940s, these calls were made from a devices weighing around 35 kgs. The first truly mobile phone call was made in 1973, it was done using a hand held device invented by Motorola. In 1983 Motorola launched its DynaTac mobile phone to the market, this was the first commercial mobile phone. The device cost around $4000 [14]. These phones worked off the first-generation (1G) network. It was not until the arrival of second-generation GSM technology and thanks to lower priced handsets that mobile phones really began penetrating mass markets. The development of the mobile phone occurred at a rapid pace; mobile handset weight was continually reduced from close to 800 g to less than 160 g in only 20 years (Fig. 3). At the same time the price of handsets fell from over £2500 to less than £250 (Fig. 4). Costs have in recent years begun to rise due to increasing functionality through added capabilities. It is remarkable that handsets were continually improved and at the same time cost reductions were achieved.

Infrastructural investment

Mobile phone use would not be possible without the development of infrastructure. Consumers would not purchase a device that could not be used. As with FCVs there was a need to make a decision to invest in infrastructure before the market entry of the product could begin. The decision to invest is not an easy one, as the economic incentives to develop an infrastructure that currently has no customers are hard to identify. Nevertheless, without the development of infrastructure any technology reliant upon it will surely fail. Mobile phone infrastructure has been continually developed over the past 4 decades. An overview of the increase in network capabilities can be seen in Fig. 5 as measured by download rates, also know as band rates.

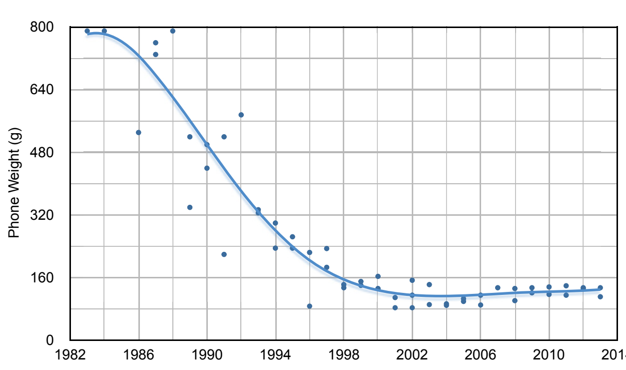

Fig. 3 – Phone handset weight from 1983-Present [15–37].

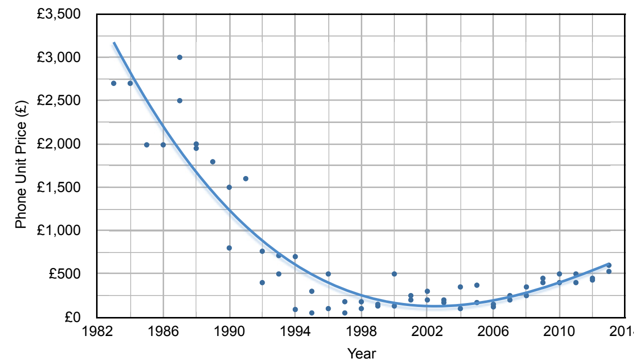

Fig. 4 – Phone handset price from 1983-Present [15–37].

Early introduction (0G)

0G networks predated mobile phone networks and were designed to support car/truck phones and mobile radio telephones. The most successful 0G network was ARP (Autoradiopuhelin) which operated in Finland between 1971 and 2000. The network managed to reach 100% population coverage by 1978 with only 140 base stations. The network quickly became congested with high demand and so Nordic Mobile Telephone (NMT) was introduced in 1981, this was a 1G network. Congestion of 0G networks was an issue in many areas including North American and most of Europe. Eventually the networks could no longer supply the high call volumes. Nevertheless these networks highlighted the potential success that a truly mobile phone and appropriate infrastructure could achieve.

First generation (1G)

Prior to the introduction of the mobile phone there existed no infrastructure that could properly support mobile communications and without this infrastructure the mobile phone would have been useless. The only comparable system was the 0G network mentioned above, but mobile phones did not use these networks. For the mobile phone a pre-development phase was needed in order to develop the necessary

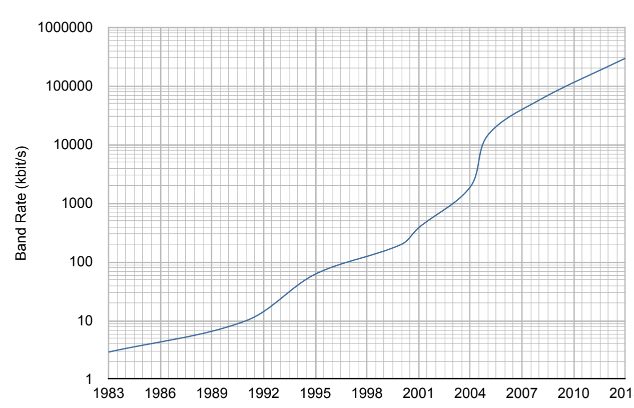

Fig. 5 – Mobile phone download band rates in Kbit/s from 1983 to 2012 [38–40].

infrastructure to support their use. A mobile phone network needed to be developed before mobile phones could be successfully marketed to the public. The first network was the first generation (1G) network; this was an analogue system and was introduced on a wide scale in the 1980s. 1G networks allowed for widespread voice communication within country borders. The first networks became operational in 1979 in Tokyo, Japan; European networks became operational in 1980 and America in Chicago, in 1977 (Kumar et al., 2010). This was 4–7 years after Motorola demonstrated the first mobile phone in 1973; this first phone call was made using just one phone mast and a short call was made locally. In 1984, 11 years after the first mobile phone call and 7 years after investments into infrastructure began, the first commercially available mobile phone was released into the market, this was the Motorola Dynatac. Astonishingly, this meant that infrastructure developers had to wait up to 7 years before they would see any return on the substantial investments that went into establishing the infrastructure at this time. Even after the launch of the Dynatac, mobile phone market penetration was still low until the 1990s (Figs. 1 and 2). It was only when prices fell below $1000 per unit (Fig. 4) that the number of subscriptions began to increase. Many of the original 1G networks were located in urban areas. Urban areas are centres of population, trade and economy, so they are perfect areas for the implementation of innovations. By initially concentrating investments in high population density areas, a relatively large proportion of the population could be covered with a limited amount of investment. Examples of this were the US mobile networks. In the US, Advanced Mobile Phone Systems (AMPS) was first launched in Chicago. This first network covered an area of 2100 square miles and comprised of only 10 base stations. Networks were then expanded from high population density areas to more remote locations as consumer uptake began to increase and were continually expanded so that they would keep up with demand (Figs. 5 and 6).

These original networks were developed within individual nations, thereby limiting usage to within the country's boundaries. Although small in comparison with todays networks, these original networks were still expensive due to not benefiting from economies of scale with large numbers of users [41]. Early networks included Advanced Mobile Phone System (AMPS), Nordic Mobile Telephone (NMT) and Total Access Communication System (TACS). AMPS became operational across most of the US in 1982.

In the US and Canada, 1G networks were launched by a system of companies headed by Bell Telephone Company [42]. This was an advantage as it lowered the amount of investment and risk each firm was required to take in order to implement the mobile network. Many of the companies investing in these networks were providers of landline telephones and radio communication companies. Crucially, mobile phone companies, such as Motorola, were involved due to their vested interest in increasing mobile phone uptake. Motorola invested both time and money into network development, inventing some of the technologies that networks used and investing in network expansions. The original network technologies were invented and patented by Motorola [43].

Second generation (2G)

The second generation (2G) network was digital rather than analogue; development began towards the end of the 1980s. The original 2G networks were known as GSM, this still being the most widespread network in the world in terms of area coverage. GSM was established to allow for pan European communication on a single digital cellular network. GSM became operational in 1991, but GSM compatible handsets did not really become available until 1992 [41]. Worldwide, 90% of mobile phone users use GSM in their voice communications [44]. GSM supported data services for the first time. It was hoped that by the end of the 20th century 20 million users would be signed up to GSM, the actual number exceeded 250 million. This was a remarkable achievement, since the GSM standard had to overcome commercial, technical and cultural

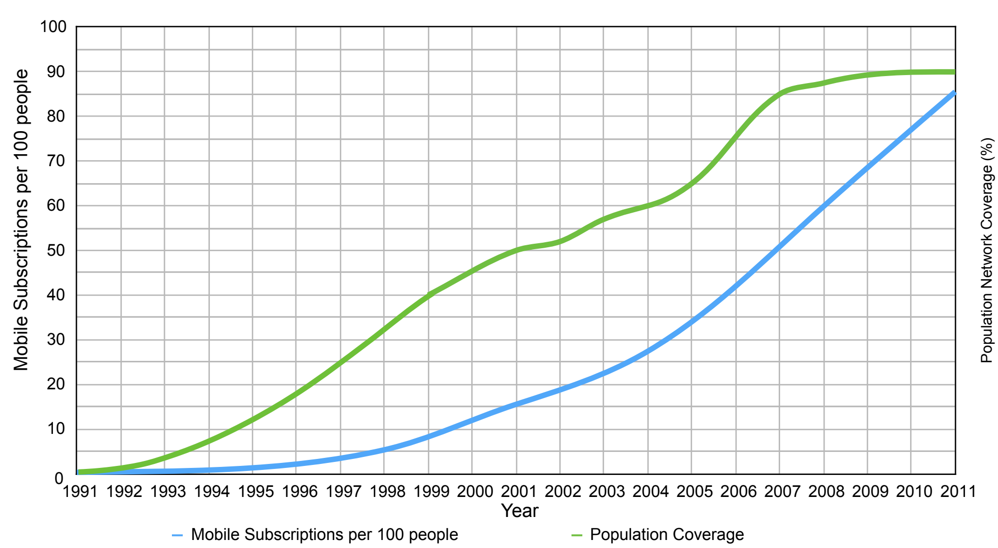

Fig. 6 – Worldwide Mobile phone market penetration and the development of mobile phone infrastructure for GSM [13,47,48].

barriers. GSM allowed for international roaming and cross border communications via mobile phones [45]. The standard was originally developed for European use, but is now used worldwide.

2G networks have been continually upgraded to cope with increased demand. The first upgrade was to 2.5G also known as GPRS and then to 2.75G also known as EDGE (Enhanced Data rate for Global Evolution). The upgrade to EDGE began in the US first in 2002 [41]. These evolutions took the mobile phone network closer to the 3G networks that are widely used today. GPRS and EDGE allowed for faster data communication and enhanced Internet access. GSM was originally only designed for voice communication. However, demand began to shift from mainly voice and text communications to data as well. GPRS and EDGE already made moves for the 3G network to arrive [45].

Third generation (3G)

In 2002 demand began to shift from mainly voice and SMS communication to increased data communication; network operators responded to the demand and began looking into increasing network capabilities, GPRS and EDGE being stop gaps until this development could be completed. The 3rd generation network became to be known as only 3G. The first commercial network became available in Japan in 2001, closely followed by South Korea in 2002 [45]. 3G allowed for a substantial increase in data and voice communication capacities over previous networks [46]. 3G is far less well distributed than the GSM network only covering around 11% [41] of global distribution compared to 80% for GSM [44]. The majority of 3G network users are in developed countries. In the UK, 99.1% of mobile phone users have access to 3G from at least one network provider [12].

Fourth generation (4G)

More than £2 billion is currently being spent by network EE to roll out the new 4G networks across the UK. 4G is also known as IMT-Advanced [40]. The 4G networks are all being launched in urban and high population areas. In the UK, 4G is available in London and surrounding areas, Cardiff, The Midlands, urban areas in the North of England, Edinburgh, Glasgow and Belfast. Only urban areas are being covered at present.

Predevelopment of infrastructure

The findings from the case study of the mobile phone have been used to develop a scenario model for the introduction of hydrogen infrastructure. Real data from the introduction of the mobile phone and the development of its infrastructure is shown Fig. 6. This data is partly taken from GSMA data, which measures the Global Coverage of GSM networks [47]. For some years before 1999 no data from GSMA is available, for these years Nokia Siemens data was used [48]. This Nokia Siemens data counts the number of networks in operation from 1991 to present. The data was converted so that it would show population coverage. The Nokia Siemens data was cross-referenced with the GSMA data for years where both data sets were available. This data was then extrapolated back from 1999 to 1991 so that the level of population coverage could be understood. Both sets of data only account for GSM networks and not more advanced 3G or 4G networks. GSM networks are by far the most wide spread globally accounting for 90% population coverage.

From the mobile phone data it is clear that infrastructure development predated mobile phone market penetration. The lag in time is between 3 and 5 years according to the data in Fig. 6.

Predevelopment of hydrogen infrastructure

Based on the findings discussed throughout section 2 and data shown in Fig. 6 implications can be drawn for the development of a hydrogen infrastructure. The main conclusion is that pre-development of infrastructure will be vital to the market introduction of FCVs. The above data have been applied to existing projections of FCV market share up until 2050. Two projections have been used. The first (Fig. 7) is based on California's Advanced Clean Car Program (CACCP) predictions [49]. These predictions represent a high level of market penetration compared to other predictions. The second scenario (Fig. 8) is based on the Department of Energy and Climate Change's (DECC) 2050 Pathways Report [50], this data set represents more conservative predictions for FCV market entry based on percentage of miles travelled by FCVs. The secondary y-axis on Figs. 7 and 8 represents the percentage of vehicle users who would need to have access to hydrogen refuelling infrastructure so that the market predictions from DECC and CACCP can be met. It is important that percentage of vehicle users is used rather than percentage of the total population. This is done so that the infrastructure numbers relate properly to the FCV market share data, which also does not measure FCVs in the entire population; the data measures the percentage of FCVs specifically within the automotive sector. Access to refuelling infrastructure is defined as a maximum travelling distance of 5 miles to a filling station.

The most outstanding message of the infrastructural development scenarios is that hydrogen infrastructure

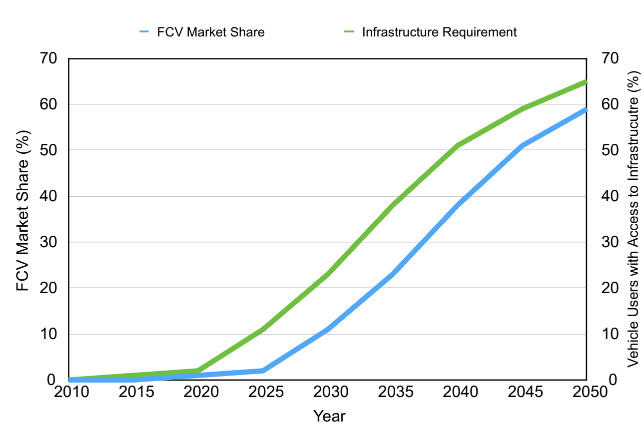

Fig. 7 – FCV Market share based on California's Advanced Clean Car program predictions of on-road light duty vehicle fleet [49] and the infrastructure that will be required in order to support this market entry.

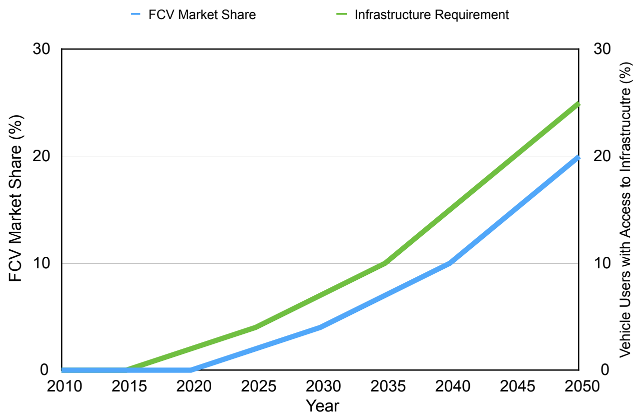

Fig. 8 – FCV Market share based on UK DECC 2050 Pathways Report miles travelled by vehicle type [50] and the infrastructure that will be required in order to support this market entry.

development must occur 3–5 years before market penetration of FCVs can be expected to occur. This 3–5 year lead-time is instrumental in creating a market demand for FCVs, and is in line with Melaina's finding [51]. Both scenarios indicate FCV market entry occurring in 2020 and reaching high market shares by 2025, this would mean that meaningful investments into a hydrogen infrastructure would need to begin by 2015–2017 and larger investments would be needed by 2020–2022. Without these investments the market uptake of FCVs could be lower than is the UK DECC and CACCP predictions.

If by 2050, according to California's Advanced Clean Car program predictions (Fig. 7), there will be 59% FCVs making up the number of light duty vehicle on Californian roads we would require 59% of the vehicle users to have access to hydrogen infrastructure by 2045 and by 2047 at the latest. Based on the DECC predictions of 20% FCV market share by 2050, 20% of the vehicle users would need access to hydrogen infrastructure by the year 2045–2047 at the latest. Prior to reaching these figures, continuous investments into hydrogen infrastructure will be needed. In the first 3–5 years it is probable that FCV market penetration would be at near 0% with the only vehicles being in demonstration projects or a small numbers of early adopters. The lack of existing markets for FCVs is unavoidable and a market will not be able to grow until some baseline hydrogen infrastructure has been constructed. The recommendation made here is that a 5-year lead-time is the best strategy for hydrogen infrastructure since this will lead to smoother market entry for FCVs. The scenarios below are all based on this 5-year lead-time. If this 5 year lead time is not in place the level of market penetration of FCVs will lag behind the predictions from the DECC and CACCP.

Now that the amount of infrastructure needed has been defined it is important to consider what is meant by access to infrastructure. FCV owners cannot be expected to travel 10s of miles in order to reach a filling station. It is assumed that the maximum theoretical distance travelled to reach a hydrogen filling station would be 5 miles. This distance is based on a study by Melaina and would mean that in the US it would take a maximum 17 min to a reach station (travelling at an average of 25mph) [51,52]. Based on these figures a quick calculation revels that to cover 100% of the UK we would need only 1198 hydrogen filling stations as an absolute minimum. This is remarkably close to the 1150 stations suggested by UK H2 Mobility [53].

For California 100% coverage could be reached with 2085 filling stations as an absolute minimum. Figs. 9 and 10 show the number of filling stations that would be required in the California and the UK respectively. These numbers are based on the DECC and CACCP scenarios. For California 21 filling stations are needed by 2015, there are currently 9 accessible to the public. For the UK where the number of vehicles is predicted to be lower 24 filling stations are needed by 2020. These figures represent the absolute minimum number of filling stations required to allow the numbers of vehicle users access to a hydrogen filling station within 5 miles. It would be more beneficial to have a greater number of filling stations to prevent congestion and to give FCV users more filling options. It is also clear that these stations would be located in strategic locations so that they are accessible by a large proportion of potential FCV users. Additionally is it important that the stations connect different areas of the country allowing for intercity as well as intra city travel.

These absolute minimum hydrogen filling station numbers mean that for the UK there would be 14,000 FCVs per 1 filling station. This would clearly be too high. The current ratio for ICE vehicles to petrol stations is 4011 vehicles per 1 station based on 34.5 million vehicles on the roads [54] and 8600 filling stations in the UK [55]. In California there is a ratio 3831 vehicles per filling station, based on 31.8 million vehicles [56] and 8300 filling stations [57]. Therefore it would be sensible to increase the number of hydrogen filling stations by a factor of at least 2 or 3 so that each filling station serves a similar number of vehicles as petrol stations serve currently. This will ensure demand for hydrogen is met. More appropriate numbers of filling stations can be seen in Figs. 11 and 12. Fig. 11 shows low, medium and high scenarios for the number of hydrogen filling stations required to meet the FCV market

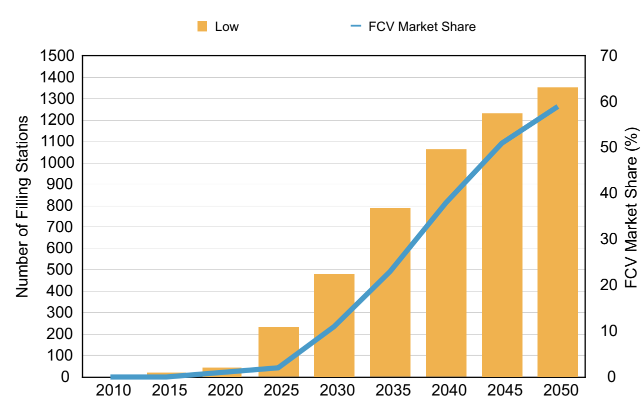

Fig. 9 – FCV Market share based on California's Advanced Clean Car program predictions of on road light duty vehicle fleet [49] and the number of hydrogen filling stations that will be required in order to support this market entry.

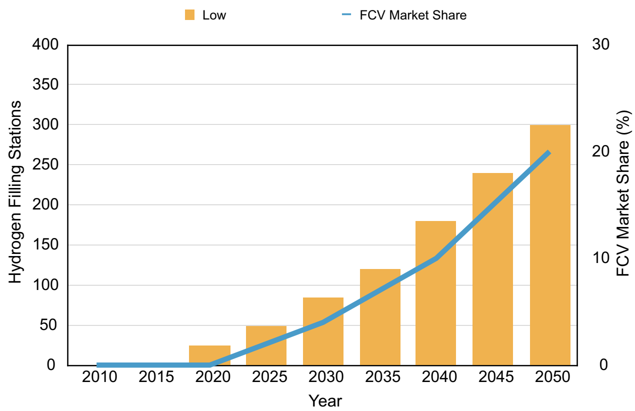

Fig. 10 – FCV Market share based on UK DECC 2050 Pathways Report miles travelled by vehicle type [50] and the number of hydrogen filling stations that will be required in order to support this market entry.

entry predictions based on California's Advanced Clean Car programme predictions of on-road light duty vehicle fleet [49]. Fig. 12 shows low, medium and high scenarios for the number of hydrogen filling stations in the UK in order to support the UK DECC 2050 Pathways Report [50] predictions for FCV market entry. Careful selection of the locations of these stations would obviously be crucial. Areas with a large number of potential early adopters of FCVs would need to be targeted first as well as areas with high proportion of vehicle users. This paper does not look at specific locations of such filling stations and there is clearly room for potential future work.

What these scenarios clearly illustrate is that there is an urgent need to invest in hydrogen infrastructure in California by 2015 and in the UK by 2020. Without this infrastructural investment uptake of FCVs will be lower than what the current scenarios are predicting. This would clearly be detrimental to the market uptake of FCVs. The 3–5 year lead-time of infrastructural development resulted in the successful introduction of the mobile phone. A 3–5 year lead-time of could also be crucial to a successful market uptake FCVs.

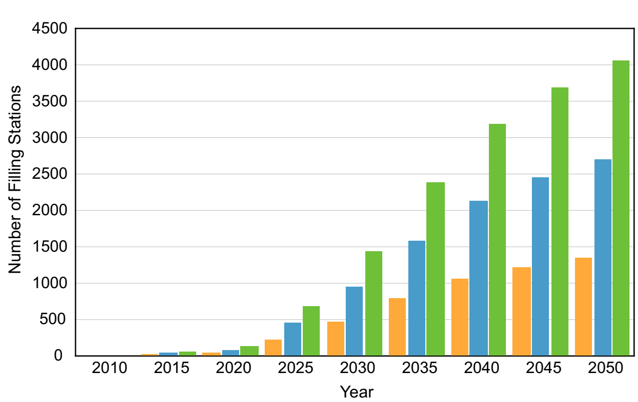

Fig. 11 – Low, Medium and High scenarios for the number of filling stations required in California to support FCV market entry based on California's Advanced Clean Car program predictions of on road light duty vehicle fleet [49].

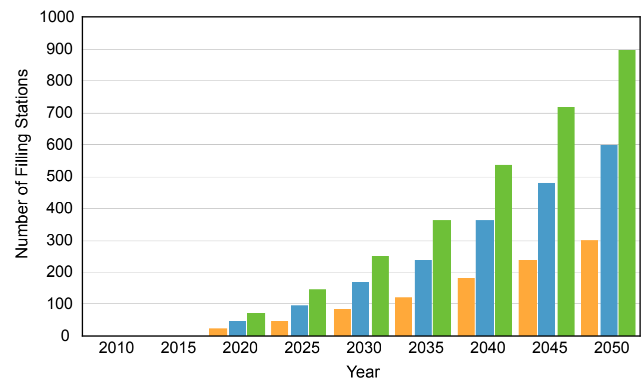

Fig. 12 – Low, Medium and High scenarios for the number of filling stations required in the UK to support FCV market entry based on the UK DECC 2050 Pathways Report [50].

Conclusion

Many developers of FCVs and hydrogen infrastructure are experiencing a predicament. There is currently no market demand for FCVs because there is no hydrogen infrastructure. Further to this, infrastructure providers will not invest into a hydrogen infrastructure because there is no demand from FCVs. The only solution to this is to pre-develop a hydrogen infrastructure in order to create a basis on which consumers can use FCVs. Major investments into infrastructure can occur in sync with market penetration, but initial infrastructural investment must pre-date market entry of a new product. The situation that exists today for FCVs existed 30 years ago for the mobile phone. But mobile phone developers, telecom infrastructure developers and telecom network providers eventually came together and jointly invested in the pre-development of mobile telecom infrastructure to support the mobile phone. The mobile phone would not have been as successful as it is today without these early investments. The organisations making the initial investments into mobile networks were both communication providers and handset OEMs. Today it is easy to see the rationale of OEMs investing into infrastructure as handset market share is more than double that of infrastructure providers market share within the mobile phone industry (15% compared to 7% of revenue) [58]. In this way investment into FC infrastructure should be done in part by incumbent oil companies, existing hydrogen producers but it is also important that automotive firms and FCV developers, invest into the infrastructure that will support their products. Automotive OEMs are often reluctant to invest into infrastructure, but they should learn lessons from Motorola and realise that investments into networks can result in increased revenue generation through increased sales of their products. With a larger number of investors involved in the introduction of a hydrogen infrastructure, costs will be lowered and risks shared. Governments are keen to see hydrogen infrastructure developed for environmental reason, energy security and social reasons. Some projects involving a large number of stakeholders are underway. The UK H2 Mobility project brings in some of the stakeholders mentioned above but does not include oil companies. The recommendations made in this paper align with those made by the UK H2 mobility project. The project outlines a roadmap to 1150 hydrogen filling stations covering the entire UK by 2030 [53]. These figures are in excess of the number of filling stations suggested here, so would be sufficient to support the market entry figures suggested by the UK DECC. If the H2 mobility project is a success it could result in the smooth market uptake of FCVs in the UK.

The California Energy Commission in the USA awarded funds for the construction of filling stations [59]. It is also important that all of these stakeholders understand that a return on their investment will not come quickly. It therefore will seem counter intuitive for them to invest, in an economic sense at least. Early investments may also serve to create a positive brand image and companies may choose to market themselves as 'green', which can lead to them generating strategic advantages over competitors. The greatest danger, if companies decide not to invest, is that they will suffer lost revenue in the future due to not succeeding in market entry with their innovations [60]. The suggestion of having automotive OEMs invest into infrastructure is a divergence from their current business models. This may not be appealing to them, but if they want to see their FCVs enter markets it may be the only sensible option.

One automotive firm, Tesla Motors, is already investing into BEV recharging infrastructure to support the market introduction of its own vehicles [61]. Supercharger stations cost between $150,000 and $300,000 and there are currently 42 in the US and 13 in Europe [61]. This means that the networks have cost between $8.25 and $16.5 million to date. FCV developers should learn from this and not be coy when considering investments into a hydrogen infrastructure.

An alternative method, although not the main recommendation being made here, is infrastructure development alongside centralised vehicle fleets. Fuel Cells are now seeing widespread applications in a number of niche markets; in both stationary and mobile power applications. One such mobile power niche is material handling equipment. Large fleets of forklift trucks are now in use [62]. These fleets are used alongside an onsite filling station that provides hydrogen. It may be possible for hydrogen infrastructure to firstly develop in these niches. FCV fleets that operate from a central hub could be operated using these centralised filling stations. This type of operation would be most useful to transport authorities and delivery companies, but could also be used to support the introduction of FCVs to the general public. This method would be less risky in terms of economic investment as there would be a guaranteed customer base; however, it is unlikely to facilitate a rapid increase in the consumer uptake of FCVs. What could be more useful is if these types of schemes were used as pilot and demonstration projects. These could indicate the success of a seed hydrogen infrastructure and convince FCV stakeholders to invest in a predevelopment of infrastructure.

Summary

There is currently a lack of commitment to the development of a hydrogen infrastructure to support FCV market entry. In order to understand how to develop a hydrogen infrastructure a historical case study of mobile telecommunication infrastructural development was done. Mobile telecommunication networks were successfully developed from scratch by a consortium of companies before mobile phones were released to market. This predevelopment of the infrastructure was key to the successful market uptake. The predevelopment lead-time for the mobile phone networks to be built was between 3 and 5 years.

In order to allow smooth market entry of FCVs predevelopment of infrastructure will be critical. By investing into hydrogen filling stations before FCVs are expected to enter markets no delay should occur and market entry should proceed as it has been foreseen. It is suggested that a 5-year lead-time is appropriate with a minimum lead-time of 3 years. The issue still remains that pre-development will be an expensive, time consuming and high-risk process. Individual companies would not be willing to undertake such an exercise. This is the reason that it is suggested that a hydrogen infrastructure is developed by vehicle manufactures, hydrogen-producing companies, existing oil companies and governments. This will allow costs and risks to be shared by all stakeholders in a hydrogen economy.

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